

Assessing the impact of micro-generation technologies on local sustainability



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ABSTRACT

The work addresses the role of local energy planning for the introduction of low carbon policies to achieve challenging climate targets. Taking as reference case an urban area that aims to become Sustainable Community, several initiatives have been assessed. Two target years, 2020 and 2050, have been analysed with the aid of EnergyPlan, an integrated energy system model based on the hourly energy demand and supply able to consider constraints deriving from grid stability. The effects of climate change, defined by a regional climate model, have been analysed in the long-term scenario. The work focuses on the impact of a high share of micro-generation technologies for satisfying the energy demand of the building sector, following an original comprehensive approach that helps a better understanding of the implication of such low carbon policy. Both solar devices and micro-combined heat and power systems have been taken into account, the latter covering different technologies (i.e. internal combustion engines, Stirling engines, microturbines and fuel cells). Results show that the use of a high share of micro-generation technologies can help to reduce CO₂ emissions and enable an increase in large-scale intermittent renewable production, only if a coordinated local energy plan combined with an optimal operation strategy is pursued. Moreover the work outlines the importance of developing an integrated energy system for introducing such technologies that can help to: (i) decarbonise the building sector, (ii) increase energy security and (iii) postpone the investments in new network capacity.

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1. Introduction

According to IPCC [1], even below the level of 2 °C of temperature increase, a significant impact in climate condition will occur, thus mitigation and adaptation policies must be introduced to increase resilience and reduce economic, environmental and social costs.

Since climate impact and vulnerability varies among regions, a bottom-up approach involving local governments must be combined with a top-down approach, involving national governments and international authorities.

Several are the initiatives launched worldwide to stress on the role that communities can play to combat climate change, such as Agenda 21, the 'EU-Cities Adapt' initiative [2] and the Covenant

of Majors frameworks, a EU program aimed at exceeding the 20% emission reduction target that has been joint by about 5 thousands cities so far.

The interest in how cities use energy resources has been enforced by an increase in urbanisation [3]. As a matter of fact, it is expected that 60% of people will be urban by 2050, with a consequent increase in CO₂ emissions and primary consumption of about 70–80% [4].

Local governments are able to influence how societal groups use energy resources, limiting their access, and influence how they adapt to climate change [5].

The involvement of Local Authorities, LAs, in the energy planning process mainly derives from: (i) the site specific nature of renewable sources, (ii) their nearer connection to citizens, who play a central role in the new energy paradigm and (iii) their privilege perspective, being the first institutional actors involved in the energy planning process.

As widely discussed in [6] LAs can act as: (i) regulator, developing building codes suitable for implementing adaptation and mitigation strategies, (ii) manager, reducing the energy consumption

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Nomenclature

BAU	Business and Usual	LPG	liquid petrol gas
EC	European Commission	MEP	Municipal Energy Plan
EVs	electric vehicles	PEM	Proton Exchange Membrane
EEX	electricity excess	PV	photovoltaic
CHP	combined heat and power	RES	renewable energy production
EU	Europe	toe	ton of oil equivalent
IPCC	intergovernmental panel of Climate change		
LA	Local Authority		

on public ownerships and (iii) promoters, supporting sustainable initiatives.

In order to correctly assess the impact of low carbon initiatives on a territory, it is necessary to consider their reciprocal influence on the energy system.

The introduction of electric vehicles, for instance, can positively or negatively affects the electricity grid depending on the timing of charging, which should be studied considering the electricity production of distributed generation [7]. The identification of the right timing can, indeed, improve the system operation avoiding investments in the infrastructure upgrades that would be necessary otherwise when decentralised energy production increases [8].

Moreover in the long-term planning, the impact of climate change needs also to be considered [9]. The analysis of the effect of climate changes can help to identify the most suitable mitigation policy, able to meet adaptation targets, thus reducing the cost for citizens. For example, the use of the thermal power recovered by CHP systems for desalination purposes in coastal areas can meet the goal of reducing the electrical deficit of a territory, while at the same time improving ground-water quality and reducing the hydro-geological risk [10].

The present paper addresses the main mitigation policies for an urban area, Corinaldo, in the Central Italy, focusing on the introduction of a high share of micro-generation and micro-combined heat and power systems for the building sector and their impact on the grid.

As highlighted by IEA recommendation [11], micro-generation is an important instrument for decarbonising the building sector, whose incidence in the total energy demand ranges between 35% [12] and 40% [13].

It has been demonstrated that micro-generation technologies can strongly help to reduce primary energy usage in buildings [14], reduce carbon dioxide emissions [15], increasing the energy security, improving the voltage profile, allowing for network capacity investments deferral [16].

The area analysed, although characterised by a number of inhabitants of about 5000, has a high incidence of energy production from renewable [17]. This is quite a common situation for very small urban areas, as demonstrated by a recent report [18], which reveals that the 67% of urban areas belonging to the highest-ranking position for renewable energy production are characterised by lower than 5000 inhabitants. Although they have more difficulties in financing initiatives, in fact, they can take advantage of a more direct connection to citizens and of the motivation of local administrations that can foster private initiatives [19].

Firstly, the paper addresses the effect of short and long-term energy policies defined by the Municipal Energy Plan considering two target years: 2020, 2050. Secondly, the work addresses the effect of a high-share of micro-generation technologies, with a focus on micro-CHP technologies to satisfy the thermal and electrical demand of buildings.

The work is organised as follows: Section 2 describes the methodology used to assess the energy scenarios; Section 3 presents the local energy system under analysis; Section 4 discusses the main policies considered; Section 5 shows the simulation results and focuses on the impact of micro-generation technologies on the grid; finally some conclusion and remarks are drawn.

2. Methodologies

2.1. Assessing future energy scenarios

In order to quantitatively assess the effect of low carbon policies in terms of primary energy consumption and emissions, the work uses EnergyPlan, a software tool developed by the Sustainable Energy Planning Group of Aalborg University, in Denmark [20].

The model is an integrated energy system model, designed to analyse national and regional energy planning strategies [21], based on the hourly energy demand and supply and considering constraints deriving from grid stability.

The model has been widely used also to analyse the integration of intermittent renewable technologies (e.g. wind energy) on the energy system [22], for which considering the hourly profiles is fundamental to assess their actual impact [23].

Taking into account a yearly resolution of demand and supply, the tool considers the electrical and thermal energy supply/demand mismatch, the technical constraints for the grid stabilization and the intermittence of renewable production.

Several parameters must be introduced in order to simulate the energy system, such as: (i) electrical and thermal demand and profiles of all the economic sectors (i.e. transport, building, industry), (ii) global electricity demand (iii) energy supply (iv) characteristics of the energy conversion technologies used to satisfy the energy needs (e.g. electric efficiency of CHP plants, boiler efficiency).

Furthermore the user can introduce the optimisation strategy to be followed in the operation of the energy system, which can be either technical or market optimisation. The former minimises the import/export of electricity seeking to identify the least fuel-consuming solution, the latter identifies the least-cost solution on the basis of the business-economic costs of each production unit.

The main features of the model can be summed up as follows: (i) it is a deterministic model, as opposed to stochastic one, (ii) it describes the system on an aggregated basis, (iii) it provides the possibility to introduce different optimisation strategies, (iv) it analyses one year in one hour steps.

Fig. 1 shows the structure of the model, which is based on the simulation of different sub-systems that together form the entire energy system.

As shown in the Fig. 1 the model considers the characteristics of both fossil fuels and renewable generation supply, as well as the

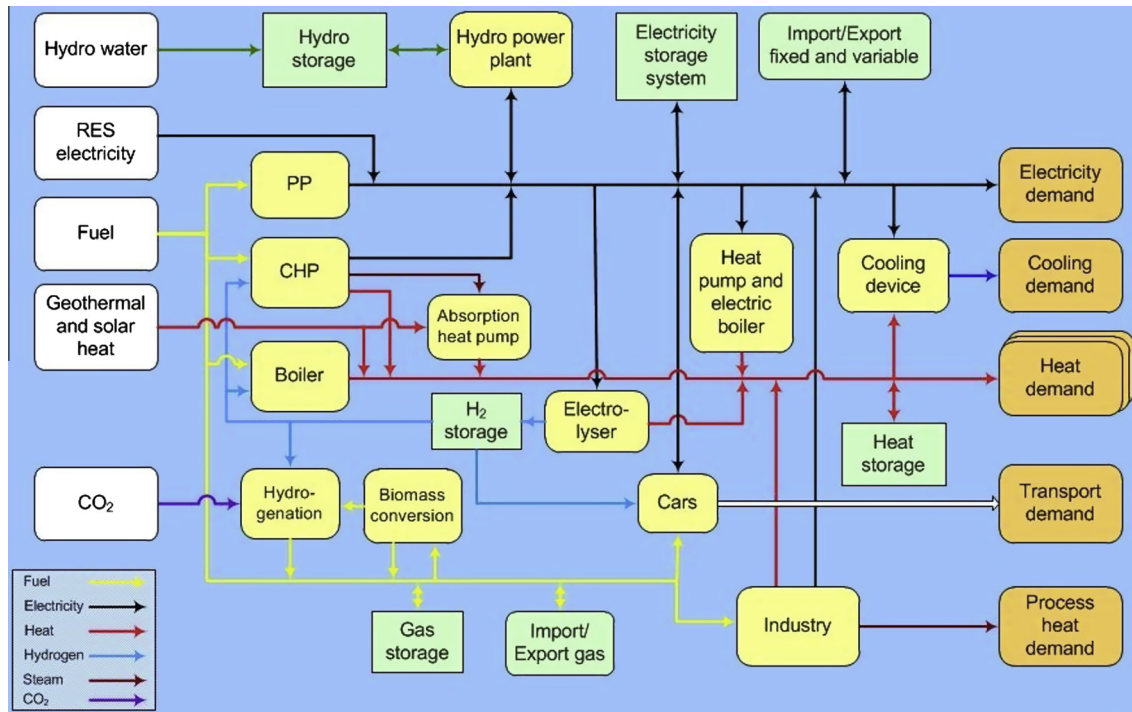


Fig. 1. Overall sketch of EnergyPlan model [20].

energy demand of industry, buildings and transport sector. Furthermore it includes a large number of conversion and storage technologies [24].

For the present work a technical optimisation is followed, considering the balancing of heat and electricity. Moreover, in the assessment of the impact of micro-CHP devices a technical optimisation approach, following only the thermal demand is also considered.

Two target years have been analysed: (i) 2020, which is the target year of the EU climate package and the Covenant of Majors and (ii) 2050, in order to appreciate the effect of long-term energy policy together with the impact of climate change. For each scenario, both Business and Usual, BAU scenario and Municipal Energy Planning, MEP scenario have been studied, the first assessing the effect of national energy policy while the second evaluating the additional contribution of local energy initiatives.

In detail, BAU scenario is based on current or soon-to-be adopted national policies. The main policies implemented are:

- reduction in electricity consumption of public and private lighting,
- reduction in electricity consumption of industry sector through inverters, high-efficiency electric motors, high-efficiency lamps,
- introduction of high efficiency lighting and household equipment for private and public sector,
- thermal insulation in private and public buildings,
- replacement of electric boiler with solar collector,
- comply with high energy standards for new buildings,
- introduction of vehicles characterised by higher efficiency due to the technology improvement.

The Municipal Energy Planning scenario, MEP, mainly considers: (i) the same national low carbon policies with a higher penetration rate derived from local information campaigns and (ii) the introduction of local renewable energy generation on the basis of the potential defined by the local energy plan [25].

A wider explanation of the low carbon policies analysed, together with the main parameters used, have been discussed and reported in Section 4 and, more precisely in Table 4.

The 2050 scenario takes into consideration the impact of climate change, implementing results derived from a regional climate model developed by [26] for the Marche Region, the administrative division to which the local area belongs. It is worthy of note that the shorter horizontal resolution used by regional climate models, of about 0.3 km, better characterised the effect of local climate changes, with respect to standard models characterised by a horizontal resolution of about 300 km.

In details, the regional model developed assesses multi-model projections coming from a set of Regional Climate Models over Europe, in particular the mean changes over Marche region in precipitation and temperature projected for the middle and ending part of the 21st century, focusing on the summer season [27].

The authors pointed out that summer is the most affected season by drying and warming conditions, with a consequence increase in cooling consumption for buildings. Thus, a cooling demand for the household has been considered in the 2050 energy scenarios.

2.2. Assessing the introduction of micro-generation technologies

According to [28], micro-generation technologies are defined as distributed generation whose electricity and thermal production is, respectively, lower than 50 kW_e and 300 kW_{th}.

As far as the analysis of the impact of micro-generation technology is concerned, starting from the 2050 reference scenario, in addition to the introduction of solar systems in public and private buildings, it has been assumed to introduce micro-CHP technologies to cover, respectively, the 25% and 50% of the thermal demand of buildings.

Micro-combined heat and power systems can reach a global efficiency significantly higher than the traditional energy conversion systems based on separate energy production, with a consequent reduction in CO₂ emission and lower operating costs [29].

Several technologies have been considered: Internal Combustion Engines, ICE, micro-combined heat and power technologies, Stirling engines and fuel cells.

Internal combustion engines are characterised by the lowest capital cost and interesting value of electrical efficiency [30]. Microturbines represent a promising technology thanks to their lower maintenance deriving from few moving parts, longer life-time, and very low emissions [31]. Stirling engines are characterised by good performance at partial load, low emissions, and fuel flexibility [32]. Finally fuel cells are the most attracting technologies in medium-long term, due to their high electrical efficiency, although capital intensive. For the present paper a Proton Exchange Membrane, PEM, fuel cell has been considered since for small-scale application they provide the highest overall efficiency, and running at 90 °C have less problems with materials used [33].

The main characteristics of the micro-cogeneration systems under analysis are shown in Table 1.

EnergyPlan follows a simplified approach to simulate micro-CHP performances, taking into account only steady state operation, since the tool is aimed at developing a comprehensive analysis of the impact of different technologies on the entire energy system, rather than investigate a single energy conversion system.

Although, it is worth noting that transient operation can have a significant effect on CHP performance, especially on heat production [34], in particular for technologies like fuel cells, where the complexity of thermochemical and fluid mechanics phenomena make necessary consider the transient response [35].

3. Case study

3.1. Local energy system analysed

Corinaldo is a preserved medieval town in the Central Italy belonging to Marche Region, one of the 20 Italian administrative divisions. It is characterised by a population of 5152 inhabitants with a density of 106 inhabitants per km². In order to assess the emission reduction coming from low carbon initiatives, year 2004 has been taken as reference year, since the implementation of energy savings and RES technologies started from 2008. Table 2 shows the energy consumption of the area under analysis in 2004, and the forecasted energy demand in 2020 and 2050, calculated on the basis of the annual rate of growth, which have been assessed on the basis of the current energy consumption data available from the Municipal energy Master Plan [25] and literature [6].

Almost 30% of dwellings are not connected to the natural gas grid, thus their energy demand is satisfied by LPG and oil gas. Figs. 2 and 3 show, respectively the final electricity and thermal demand by sector.

The 63% of electricity consumption derives from the local industry, while natural gas consumption is mainly affected by the household sector. Table 3 shows the consumption of fuels used to satisfy the energy demand of the area, together with the carbon dioxide emissions, to which results coming from the simulations will be compared.

In the following analysis, particular attention has been paid to the energy demand of public ownerships. As a matter of fact the promotion of low carbon actions in public properties can reduce

Table 2
Energy demand in 2004, 2020 and 2050.

	Energy demand			Annual rate of increase (%)
	2004	2020	2050	
Transport	31.26	32.96	34.51	0.3
Thermal demand				
Buildings	24.54	30.20	27.19	1
Industry	3.21	3.48	4.04	0.5
Electricity use	26.10	29.18	35.26	0.7

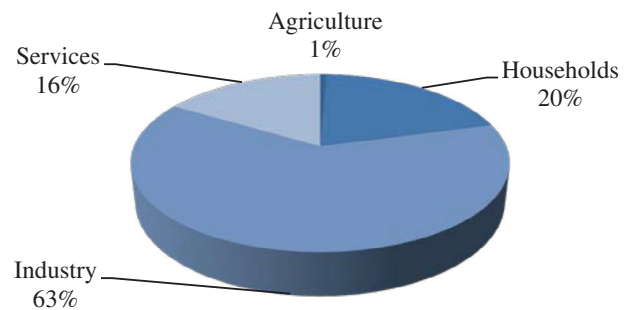


Fig. 2. Electricity consumption by sector.

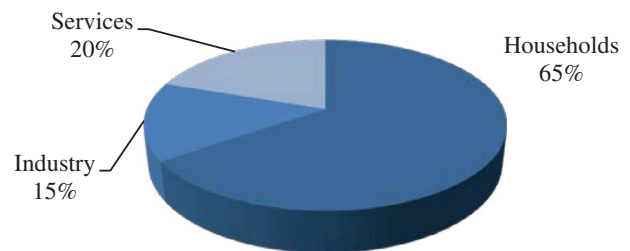


Fig. 3. Thermal consumption by sector.

Table 3
Consumption of energy commodities to satisfy the energy demand in 2004.

Fuel	Value (GW h/year)	CO ₂ emissions (ton CO ₂ /year)
Coil	13.79	4.67
Oil	45.43	12.10
Natural gas	57.73	11.66
Biomass	2.55	0
Total	119.5	28.43

the administrative energy expenditure and create important indirect effect, such as the steering the private sector in the direction of green-economy, encouraging private initiatives, supporting business network to exploit renewable sources [36].

Figs. 4 and 5 show the thermal and the electrical demand of LA properties. Considering the thermal demand, schools are the most energy demanding end-user, followed by offices and sport facilities. In the area of electricity demand the 61% derives from public lighting, for which specific actions have been studied, followed by schools, offices and sport facilities.

4. Low carbon measures implemented in the energy scenario

The present paragraph discusses the energy policies implemented in the scenarios analysed, which comprise national policies (BAU scenarios) and local policies discussed in the Municipal Energy Plan available in the website [25] that was developed with the aid of some of the authors [19].

Table 1
Technical and economic parameters of micro-CHP devices [34].

	ICE	Stirling	Microturbine	PEM
Electrical efficiency (%)	32	18	26	40
Thermal efficiency (%)	51	72	52	40
Power to heat ratio	0.59	0.25	0.5	1

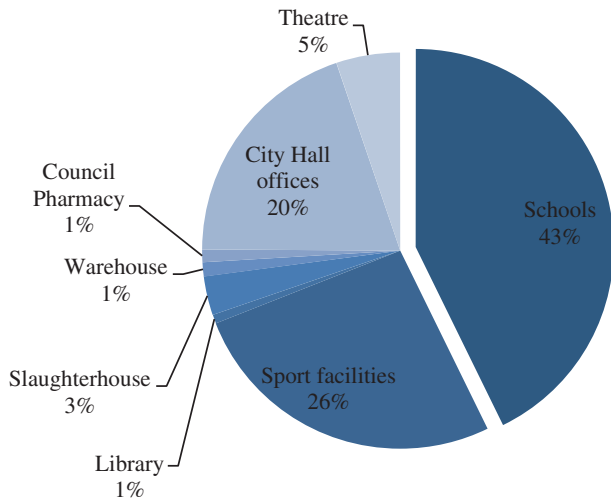


Fig. 4. Thermal demand of LA's properties.

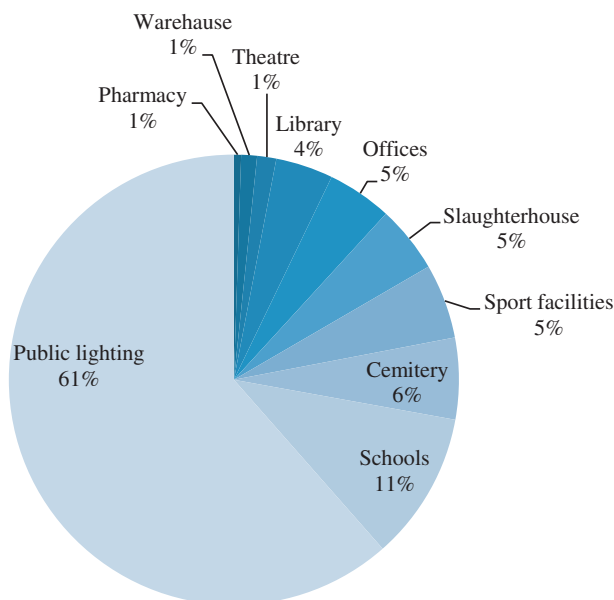


Fig. 5. Electrical demand of LA's properties.

The energy saving policies studied have been implemented as a reduction in energy demand that has been defined on the basis of: (i) either standard cases or data coming from energy audits and (ii) penetration rates, which have been assumed to increase from 2020 to 2050 target year.

Table 4 shows a synoptic diagram of the energy saving initiatives, together with the assumptions and the main parameters used to calculate the reduction of the sector energy demand. Table 5 shows the resulting energy demand used to build the scenarios. The cooling demand in the household sector has been considered only in 2050 target year, as effect of climate changes.

One of the highest contributions in energy savings derives from actions in the building sector, in particular the thermal insulation of existing buildings, since 90% of them were built before 1991, the year when an important law on energy efficiency was enacted [37]. As shown in Table 4, taking as reference case a 100 m² apartment, a reduction in energy consumption of 0.16 toe/dwelling can be achieved.

Moreover, since 30% of dwellings use heating boiler fed by LPG, it has been studied the introduction of higher efficiency heating

boilers by 2020, and innovative micro-CHP units fuelled by LPG by 2050. The innovative unit is based on Stirling technology and has been previously studied by some of the authors [32]. In particular, it applies a regenerative heat exchanger to recover part of the thermal power discharged and not recovered when the heat demand is low to increase the electric efficiency of the micro-CHP system and its power-to-heat ratio. Taking as reference case a detached house in the area a primary energy saving of 25% has been considered.

A reduction in electricity consumption can also be obtained from initiatives in industry sector, whose consumption, as shown in Fig. 2, is mainly electrical. Considering the electricity distribution derived from a national study [38] according to which the 4% of electricity demand derives from lightings, 75% from electric motors and 21% from process, it has been assumed to introduce high efficiency lighting, motors and inverters.

As previously introduced, among energy savings, particular stress has been given to actions in public ownerships, although their incidence in the total energy demand is low.

As regards schools, which represent the most energy demanding end-user, it has been assumed a 30% primary energy reduction. The value derives from the analysis of a standard case of 10,000 m³ volume, built before 1970, in which double glazed windows and external wall insulation are introduced in order to meet the energy standards defined by the decree 59/2009 [39]. It has been assumed that by 2050 all the schools are in line with the energy standards.

In the field of public lighting, two are the measures analysed: (i) the replacement of incandescent lamps with LED lamps technology for traffic lights and (ii) the replacement of mercury lamps with LED technology lamps for street lighting (see Table 4). Also in this case, the difference between 2020 and 2050 scenario is the penetration rate assumed.

Except from specific energy actions defined by the Municipality under analysis, in particular in the field of renewable production, most of the actions considered in the BAU and MEP scenarios are in common. However a higher penetration rate is considered in the MEP scenario for specific actions (i.e. public lighting, thermal insulation in buildings), which can be favoured by a more precise analysis conducted at local level and by informative campaigns able to steer the private sector toward a low carbon society.

As regards renewable energy systems, the potential generation capacity defined by the Municipal Energy Plan is shown in Table 6 and mainly attributed to the MEP scenarios.

An interesting contribution comes from landfill gas produced by the natural anaerobic digestion of wastes, which come from the surrounding territories. The cogeneration facility studied, and just implemented, has an electrical power output of 1600 kW_e.

The use of landfill gas coming from wastes is an interesting application that helps the Local Administration to solve an important problem [40]. The presence of landfill gas in the garbage dump, in fact, can lead both to possible methane combustion or, even worst, to an auto-ignition, and a direct emission of methane has to be avoided, since its Global Warming Potential is twenty-one times higher than carbon dioxide.

Another important contribution derives from PhotoVoltaic, PV, energy production, which is worldwide considered a strategic energy source in particular for the building sector, for its passive and active contribution and its correlation to the energy load [41]. Furthermore, the local area under analysis can take advantage of a good value of the local solar irradiation, of about 1300 kW h/year.

It is worthy of note that at the end of 2011, 10 MW of PV systems was already installed in the area under analysis. This high level of solar production, in addition to the highly reworded Italian

Table 4

Low carbon measures introduced.

Energy policy studied	Assumptions	Parameters used [6,41]	2020 BAU	2020 MEP	2050 BAU	2050 MEP
Thermal insulation public buildings	Schools: Replacement of single-glazed window with double-glazed window;	30% energy reduction of thermal demand		X		X
Thermal insulation private buildings	Replacement of buildings built before 1991 Thermal-insulation parameters defined by Law 192/2005 [42] and Decree 311/2006, 59/2009, 8/2011 [43–45]; Applications of the BAT and materials;	0.16 toe/dwelling Standard case: 100 m ² apartment	X	X	X	X
High efficiency equipment for household sector	110% refrigerator per dwellings 37% washing machines per dwellings 100% dish machine per dwellings 25% freezer per dwellings	0.016 toe/dwelling	X	X	X	X
High efficiency lighting for household sector	Introduction of high efficiency lamps	0.023 toe/dwelling	X	X	X	X
High efficiency in public lighting	Replacement of 60 W incandescent light bulk with 16 W LED (4000 operation hours) for traffic lights Replacement of 250 W Mercury Lamp, HPS, with 60 W LED (4000 operation hours)			X		X
High efficiency equipment for industry	Industry consumption distribution: 4% lightings, 75% electric motors, 21% process Penetration factor for high-efficiency lighting, high efficiency motors and inverters, of 57%, 33% and 33% [38]		X	X	X	X
New buildings following energy efficiency standard	New buildings are the 0.8% of dwellings	0.004 toe/dwelling	X	X	X	X
Introduction of solar heating for household sector	Use of solar collectors	0.014 toe/m ² /year	X	X	X	X
Improvement in thermal efficiency of LPG boiler	Thermal efficiency of 90% by 2020		X	X	X	X
Introduction of micro-CHP fuelled by LPG	Detached house described in Ref. [33]	25% primary energy reduction			X	X
Introduction of plug-in EV	Charging time: 10 p.m.–7 a.m.	5 km/kW h			X	X
Energy efficiency policy in transport sector [46]	Car sharing					

supporting scheme (which has been recently concluded), mainly derives from the local policies developed by the Public Administration (thus mainly consider in the MEP scenario).

In particular, investments in PV production has increased since 2008, when the Local Government developed specific guidelines to identify areas suitable for the implementation of PV plants aimed at preserving the typical municipal landscape and simplifying administrative procedures.

In the same guidelines, well-aware of the need to attract private financial support to install PV systems in public areas, a compensation criterion was defined, according to which each 100 kW_e of ground mounted PV power plant installed by a private investor requires the installation of 1 kW_e in a public area. Currently, the 50% of the electrical demand of public buildings is covered by the electricity production from PV systems.

Finally a potential contribution from river-hydroelectric plants has been introduced, in particular a 491 kW_e has been considered for the 2020 MEP scenario, and other two plants of respectively 99 kW_e, and 187 kW_e has been introduced in the MEP by 2050. All these values derive from local energy studies as reported in the Municipal Energy Plan [25].

5. Simulation results and discussion

The present paragraph shows the main simulation results of the two target years, considering all the energy policies discussed in the previous paragraph and focusing on the impact of a high share of micro-generation technologies on the energy system.

5.1. 2020 Scenarios

Fig. 6 shows the energy supply necessary to satisfy the energy demand as defined in Table 4. RES electricity stands for electricity production from solar and river-hydro systems, while the energy supply by biomass refers to both the electricity imported from the grid and electricity by biogas production.

The outside world in terms of electricity production has been simulated as a power plant characterised by an electrical efficiency of 46%, whose fuel mix by 2020 is 24.3% coal, 12.3% oil, 58.9% natural gas, 0.45% biomass [47].

The main findings of 2020 scenario are:

- slight decrease in the energy supply from fossil fuels (i.e. natural gas, coal) in BAU scenario thanks to the national policies considered,
- marked decrease in the natural gas consumption of MEP scenario, derived from low carbon policies in private and public buildings,
- increase in RES generation in MEP scenario coming from biogas, PV and river-hydro technology.

Fig. 6 also shows that the total energy supply in the MEP scenario is higher than the total energy supply in the BAU scenario, suggesting that part of the power produced by renewable is injected in the grid. This is due to the high production coming from PV systems, mainly in summer period, when the electricity demand of the area is lower than the power production, as shown in Fig. 7.

Table 5

Energy demand coming from the energy saving policies implemented.

Commodities/sector		Energy demand [GW h]			
		2020 BAU	2020 MEP	2050 BAU	2050 MEP
Electricity		24.35	24.50	24.08	23.80
Cooling	Air conditioning			0.162	0.162
Thermal demand Industry	Natural gas	3.21	3.21	2.42	2.42
Thermal demand buildings	Natural gas	16.20	15.30	15.30	14.31
	LPG	7.20	7.20	4.50	4.50
Transport	Diesel	16	16	14	11.7
	Petrol	9	9	9	5
	Natural gas		1.3	2	2.5
	LPG	2.5	2.5	2.5	2.02
	Electricity				2.03

Table 6

Renewable generation capacity introduced in the energy scenarios analysed.

	Capacity installed				Energy production per year			
	PV (MW)	ST (m ²)	Biogas (MW)	River-hydro (MW)	PV (GW h)	ST (GW h)	Biogas (GW h)	River-hydro (GW h)
2020 BAU	0.7	1837			0.88	0.30		
2020 MEP	10	3306	1.6	0.491	12.46	0.54	3.49	1.72
2050 BAU	10	5265		0.491	12.46	0.86	1.75	1.72
2050 MEP	12	5755		0.770	14.95	0.94	1.75	2.70

This situation suggests the importance of a correct energy planning at local level in order to maximise the self-consumption of renewable energy produced, able to reduce the impact on the grid, also maximising the economic result. A possible solution, as shown in [47], is the introduction of specific technologies, such as heat pumps for climate conditioning and plug-in electric vehicles.

Fig. 8 shows the CO₂ emissions of the scenarios analysed compared to 2004 scenario, when no energy saving policies were implemented yet. It can be observed: (i) a 10.45% in BAU scenario with respect to the 2004 one, (ii) 20% CO₂ emissions reduction coming from municipal low carbon initiatives, in line with 2020 EU climate target and the requirement of the Covenant of Majors.

It is worthy of note that emissions derived from biomass are those coming from biogas, in particular from the transport of wastes necessary to produce biogas.

5.2. 2020 Scenarios

Fig. 6 also shows the energy supply of the 2050 BAU and MEP scenarios compared to 2004 scenario. In this case, as above-mentioned, a cooling demand in summer period has been considered. The electricity mix assumed in 2050 energy scenario is: 20% from coal, 10% from oil, 64% from natural gas and 0.6% from biomass.

Since additional energy saving policies and higher penetration rate have been introduced with respect to the previous scenarios,

the result is a reduction in the total energy supply from fossil fuels able to compensate the increase of the energy demand.

The 2050 BAU scenario shows a reduction in: (i) oil supply mainly derived from energy policies for transport sector defined at nation level (ii) coal consumption coming from the different electricity mix assumed and (iii) natural gas consumption due to energy saving policies in dwelling sector.

The production of renewable energy increases, thanks to the implementation of additional PV plants and river-hydro systems, although there is a natural decline of electricity production from landfill biogas (see Table 6).

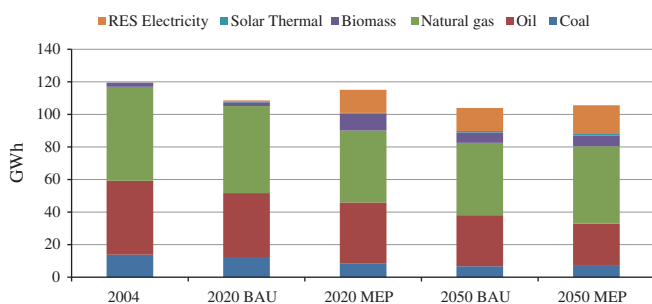
Since no policies have been considered for increasing the self-consumption of electricity from renewable, the increase of renewable generation provides an increase in excess power injected in the grid. It is worth noting that in such situation, the cooling demand derived from climate changes, which occur in summer period, is almost totally covered by the electricity produced by PV systems, which increases in summer months, providing a positive effect in the grid stability.

Fig. 8 shows the reduction in CO₂ emissions in BAU and MEP scenario compared to 2004. Thanks to energy saving policies and renewable production the CO₂ emissions in the BAU and MEP scenarios is of respectively, 29% and 30% despite of the increase in energy demand.

6.1. The impact of micro-generation on the energy system

Considering the 2050 MEP scenario, it has been assessed the effect of a high share of micro-generation technologies on the community, widely considered a key policy for decarbonising the building sector. In higher integrated energy systems, micro-generation technologies can also be used to balance intermittency in large-scale supply. It has been demonstrated that under specific conditions they can even benefit power network, improving voltage profiles and decreasing grid losses [22].

In the area analysed, in 2013 the 5% of PV systems belongs to micro-generation category. Assuming that, in 2050, micro PV systems are in a range between 5% and 10%, Fig. 9 shows the yearly

**Fig. 6.** Energy supply of the scenarios analysed compared to 2004.

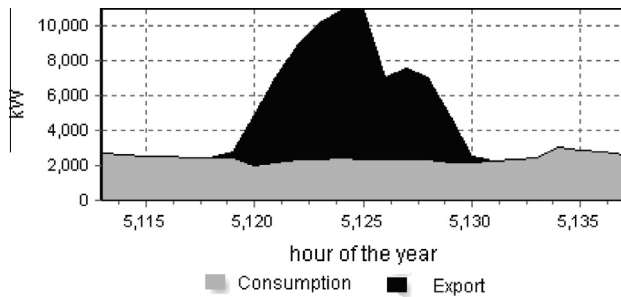


Fig. 7. Electricity production and consumption in a typical day of August.

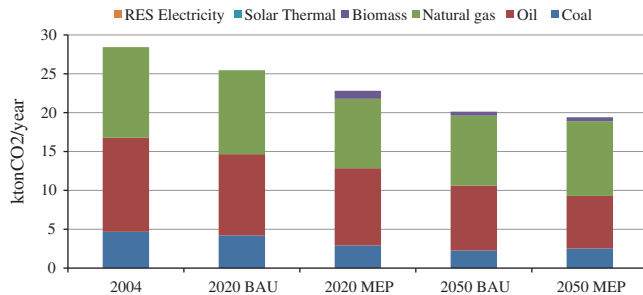


Fig. 8. CO₂ emissions of 2004 and 2020 energy scenarios.

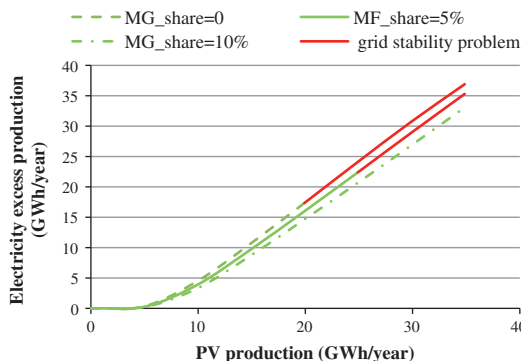


Fig. 9. Electricity excess diagram assuming that all PV micro-generation system can be used for stability purposes.

electricity injected in the grid when micro-generation devices are used to balance intermittency.

Results show that the solution proposed provides both a reduction in excess electricity and an increase in large-scale intermittent energy production, avoiding grid stabilisation problems. In case of 5% and 10% of micro PV systems used for balance purposes, respectively, 25 GW h/year and 35 GW h/year from solar production can

be introduced in the area of Corinaldo without any problems for the grid, in terms of stability, poor quality and operational safety.

The introduction of a high share of renewable generation entails, indeed, several drawbacks in electrical networks' operation, which need to be addressed in order to guarantee the quality of supply and continuity of service. Most problems affect the medium and low voltage networks, such as: odd voltage profiles, overload components, increase in short circuit power and incorrect operation of protection systems [35].

An additional problem of the entire administrative division, to which Corinaldo belongs, is the lack of network capacity to evacuate excess renewable production [48], for solving which, the European Transmission System Operator, has proposed to build a 380 kV transmission line [49].

The new high transmission line is aimed to: (i) transmit power of future generation, (ii) provide 400 MW of additional capacity derived from a more efficient operation, (iii) ensuring an acceptable voltage levels in subordinated medium and low voltage systems, (iv) improving the operational safety, quality of supply and continuity of the service.

Another interesting application of micro-generation systems to increase the introduction of intermittent sources is the use of hybrid renewable systems made up of micro-CHP technologies and intermittent renewable sources [50]. As demonstrated by [51], such solution can also increase the energy savings achievable.

Finally it has been focused on the impact of micro-CHP systems for the contemporary satisfaction of electricity and heat demand in building sector.

It has been assumed to introduce an increasing percentage of micro-CHP systems able to cover, respectively the 25% and 50% of thermal demand for buildings.

As described in paragraph 2.2, four different technologies are considered: (i) ICE, (ii) micro-turbine, (iii) Stirling engines and (iv) PEM fuel cell.

The EnergyPlan model allows the introduction of a single technology, since a single value for electricity and thermal efficiency is required.

Two different technical regulation strategies have been followed in the analysis:

- balancing heat demand,
- balancing both heat and electricity demand, reducing micro-generation systems when necessary for grid stabilization.

In the first case, micro-CHP technologies are assumed to follow the thermal demand and to inject the power produced and not immediately used in the electricity grid, since they are in parallel to the grid.

It is worthy of note that the tool gives the possibility to define only the aggregate thermal demand of the entire building sector.

Table 7
Renewable generation capacity introduced in the energy scenarios analysed.

	CO ₂		EEX		NG consumption	
	Thermal load balancing	Electrical and thermal load balancing	Thermal load balancing	Electrical and thermal load balancing	Thermal load balancing	Electrical and thermal load balancing
25%						
ICE	19.54	19.35	14.03	13.46	38.95	38.58
SE	19.50	19.46	13.55	13.40	39.74	39.65
μGT	19.62	19.47	13.86	13.44	39.23	38.95
PEM	19.63	19.23	15.04	13.76	38.36	37.68
50%						
ICE	19.87	19.14	16.14	13.85	48.82	45.76
SE	19.39	19.26	13.89	16.44	45.07	44.55
μGT	19.90	19.43	15.33	13.77	48.77	46.66
PEM	21.12	19.39	20.23	14.98	54.67	47.50

Table 7 shows the main results, in terms of primary energy consumption, carbon dioxide emissions and NG consumption.

The balancing of thermal demand gives, in most cases, the highest values of primary energy consumption and excess power to be injected in the grid.

In this case the best technology is Stirling engine, because, working in thermal priority, its overall efficiency is higher than other technologies. Furthermore the lower electrical production reduces problem of excess electricity.

Comparing this scenario with 2050 MEP scenario, there is an increase in CO₂ emissions, due to an increase in natural gas consumption.

However, also considering a 50% coverage of building thermal demand, there are no problems in terms of grid stability.

The second optimal strategy gives the best results in terms of both CO₂ emissions and excess power injected in the grid, improving climate targets achievable, if compared to MEP scenario. Results outline the advantage coming from the introduction of micro-CHP technology, when correctly planned and operated.

As regards technologies, in the 25% case, PEM fuel cells that are characterised by the highest power to heat ratio and electrical efficiency provide the best results. In the 50% case, ICEs provide the lowest values of CO₂ emissions, while micro-turbines guarantee the lowest power excess. Also in these cases, no problems in grid stability are recorded. Those findings suggest the importance of a correct management of micro-generation systems, which ask for a highly coordinated and integrated energy system.

6. Conclusion

The work addresses the effect of local energy policies for the achievement of challenging climate targets, focusing on the impact of micro-generation technologies on the energy systems. The originality of the paper stands in the comprehensive approach aimed at understanding the impact of micro-generation technologies on an entire community, based on actual data coming from the local energy plan.

Higher CO₂ emissions reductions can be achieved thanks to a coordinated local energy plan, since criticalities as well as proper actions can be better studied and implemented. Although the space of manoeuvre of Local Administration is limited, they can undertake important exemplary actions and increase the awareness of citizens about environmental concerns.

Two reference years have been analysed, 2020 and 2050, the latter considering also the impact of climate changes, which need to be evaluated by local climate models in order to correctly assess the actual effect. In the case studied, an increase in cooling demand can be almost completely satisfied by PV energy production exported to the grid, even reducing the problem of excess electricity. The result suggests the importance of combining mitigation and adaptation strategies to reduce environmental and social costs.

The analysis focuses, furthermore, on the impact of micro-generation systems on local sustainability. The area under analysis is characterised by a high percentage of renewable generation by intermittent sources, which in authors' opinion, could be a common case by 2050, due to the widespread of supporting policy mechanisms to combat climate changes. In such case the introduction of micro-generation technologies needs to be correctly planned and managed in order to: (i) provide the best results in terms of CO₂ emission reduction, (ii) increase the grid stability, (iii) enable a higher percentage of large-scale intermittent renewable production, thus postponing investment on the grid. In line with this view, the creation of a more coordinated energy system cannot be deferred.

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